



Unlocking Underwater Connectivity

Exploring UnetStack Framework for
Subsea Communications and
Networking



1. Introduction

The Internet has significantly reshaped our lives, disrupting various industries. The marine and subsea domains being no exception. From autonomous ships to smart ports, remote ocean monitoring through telemetry buoys, marine robots, and sensors, several advancements have emerged. Terrestrial wireless networks like Satellite, 3G/4G/LTE, and long range radio play a pivotal role in enabling these innovations. However, this does not translate to the underwater domain. Many underwater robots rely on tethers, and subsea sensors store data locally for manual retrieval, highlighting the pressing need for transformative technologies in underwater connectivity to bridge the gap with the Internet's reach.



Figure 1. The future of underwater wireless

Adopting terrestrial wireless communication methods or Internet technologies such as TCP/IP for underwater use is not viable. This is primarily due to the rapid fading of electromagnetic (EM) waves (except for the optical spectrum) underwater. Acoustic systems used underwater need to deal with limited bandwidth, long latencies and challenging channel conditions. Similarly, underwater optical systems encounter limitations in communication range. Therefore, there is a need for a set of specialized technologies developed for underwater communication networks, calling for a whole new way of thinking. This motivated the creation of UnetStack – a software-defined framework for better underwater wireless communication networks that are scalable and flexible that will let us extend the Internet underwater.

UnetStack is a versatile software framework designed for underwater communication and networking. Offering a range of tools and technologies, it enables the development, configuration, and optimization of communication devices and networks beneath the waves.

2. What Is UnetStack?

UnetStack is a collection of technologies designed to extend communication networks underwater. Developed as part of the Unet project at the [ARL](#), National University of Singapore, this agent-based network technology aims to enable the creation of communication networks that expand underwater using acoustic, optical, or wired links. Such networks formed using Unet nodes — nodes powered by UnetStack — spans above and below water. For instance, to facilitate communication over underwater acoustic or optical links, dedicated modems are employed, while more conventional RF, GSM, satellite, or wired connections are accessed via standard TCP/IP interfaces. All nodes within this network operate on the UnetStack software utilizing the best links for the application at hand, unifying communication across diverse link types to provide seamless end-to-end connectivity.



Figure 2. UnetStack

This fully software-defined framework aims to provide communication technologies starting from the physical layers all the way to the application layer. It also encompasses other services such as positioning and localization, data analytics, and device and sensor management. UnetStack offers a wide range of developer tools, including the Unet simulator, dashboards, and a flexible Application Programming Interface (API) accessible in multiple languages such as Java, Groovy, Python, Julia, C, and Javascript.

3. Components Of UnetStack

So, what are these technologies that make up UnetStack? It starts with the open source agent-based messaging fabric known as fjåge on top of which the rest of the features are built upon. Fjåge, along with the Unet framework, forms the core of UnetStack. Here is a quick rundown of the various components that make up the UnetStack.

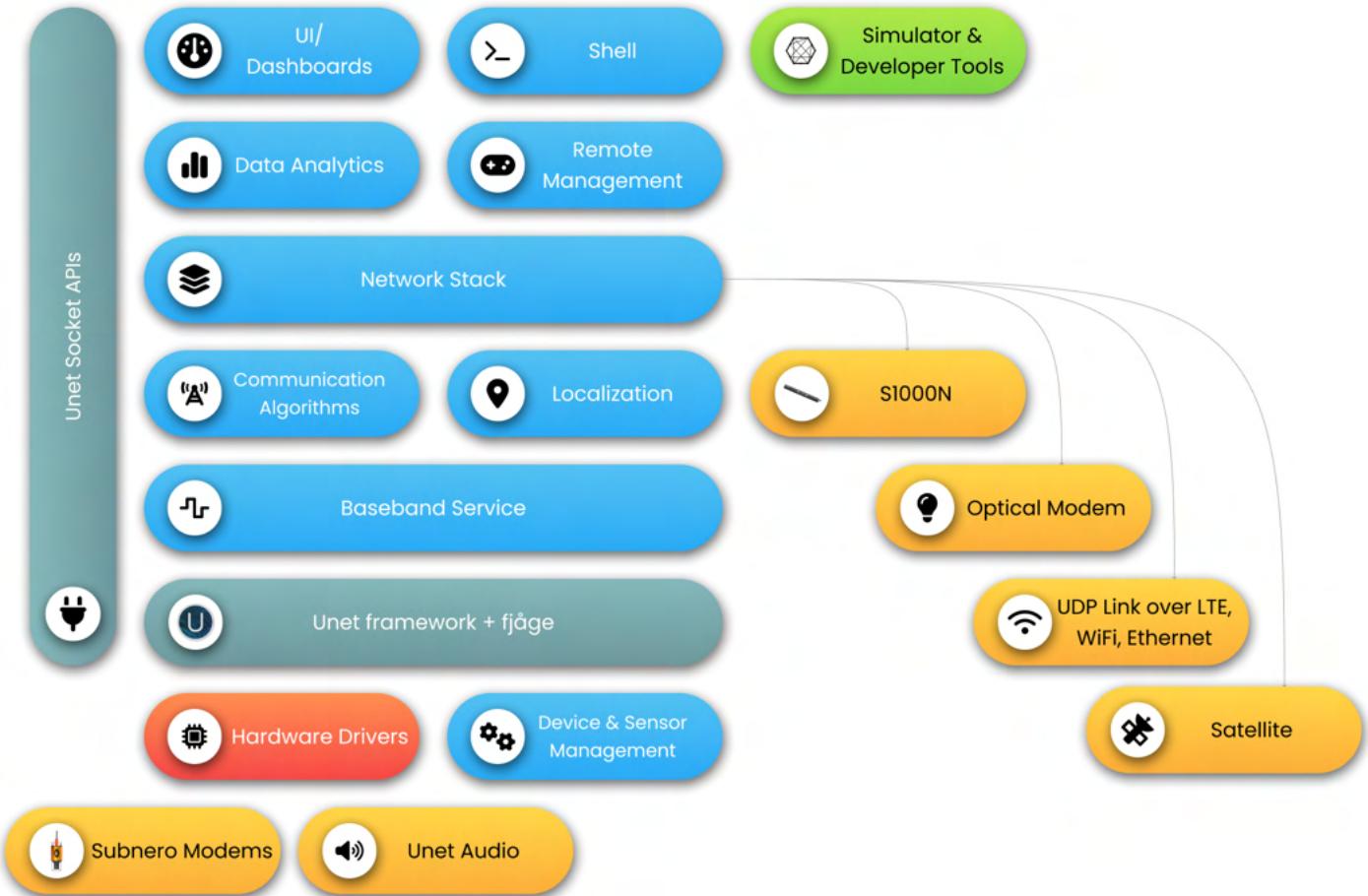


Figure 3. UnetStack Components

3.1. Core Components

Messaging Fabric (fjåge)

The lightweight and open-source fjåge (Framework for Java and Groovy Agents) form the foundation for agent-oriented software development, upon which UnetStack is built. fjåge uses JSON for communication between containers, exchanged over some form of networked transport like TCP.

Unet Framework

The unet framework provides core services, messages, agents and APIs needed by UnetStack.

Communication Algorithms, Network Stack, and Other Services

This is the collection of agents providing diverse functionalities, including physical layer, the network stack, localization, data analytics, and processing. These agents are classified into basic and premium based on their offerings and may range from fundamental services to specialized features for applications such as marine robot or underwater sensors.

3.2. UnetStack Agents

Basic Agents

A collection of agents fulfilling the essential requirements of typical underwater networks. Together with the Unet framework, these agents enable the construction of fully functional underwater networks.

Premium Agents

Encompassing agents with advanced functionalities with superior performance or application/domain specific features (e.g. marine robotics, underwater sensors), the premium agents often overlap in services with the basic agents but utilize advanced techniques for enhanced efficiency and performance.

NOTE: Depending on the deployment needs, users may choose to have a combination of basic and premium agents.

3.3. Additional Components

Unet Simulator & Channel Models

The Unet Simulator allows the user to simulate multiple nodes on a single computer. It offers both real-time and discrete event simulation modes, enabling interactive testing, Monte Carlo evaluations, and protocol performance assessments. It also supports different types of channel models.

Unet audio

Unet audio is a Software-Defined Open Architecture Modem (SDOAM) running on computers (e.g. desktops, laptops) utilizing sound cards for transmissions and receptions. It is meant to be an educational tool to aid in developing and testing network protocols and acoustic communication techniques using user's laptops. It also offers a Raspberry Pi-compatible version, enabling enthusiasts and students to build DIY modems to work in lab settings.

Unet Interfaces

UnetStack, with its fully modular and open architecture, offers a set of versatile interfaces. Users have multiple interface options, such as web-based dashboards, command shells, scripting support, Unet sockets, Portals to name a few. All of these interfaces are available in a number of computer languages.

4. Which Components Are Right For Me?

Deciding on the most suitable components for your needs might seem daunting. To simplify this process, we've categorized the various components into different editions as shown in Table 1: UnetStack Editions.

	Community Edition	Commercial Edition	OEM Edition
Simulator	✓	✓	N/A
Messaging Fabric	✓	✓	✓
Network Stack			
Basic	✓	✓	✓
Premium	—	✓	✓
Communication Algorithms			
Basic	✓	✓	✓
Premium	—	✓	✓
Channel Models			
Basic	✓	✓	N/A
Premium	—	✓	N/A
Unet Audio	✓	✓	N/A
Hardware Drivers	—	—	✓
Licensing	Free*	One-time	Volume

* For non-commercial use only.

Table 1. UnetStack Editions

4.1. Community Edition

The community edition is designed for academic users such as researchers, students, or enthusiasts interested in developing and simulating underwater networks for educational and non-commercial purposes. It contains the Unet Simulator with basic channel models and Unet basic agents. This edition is available for download on the UnetStack website, free of charge. However, note that it is solely for non-commercial and educational use. Upgrades for this edition can also be obtained from the UnetStack website, when available.

- **Platform:** Workstation (Linux, macOS, Windows)
- **Components:** Unet Simulator, Unet basic agents, basic channel models

4.2. Commercial Edition

The commercial edition is designed for use cases that may not require a specialized hardware component for commercial applications. Example use cases include simulating large underwater networks with premium agents, simulating underwater channels for planning your deployments. It contains premium agents for enhanced performance in commercial deployments tailored to user preferences. This edition includes the Unet Simulator, Unet basic and premium agents. It offers perpetual licensing for specific versions and receives bug fixes as long as supported.

- **Platform:** Workstation (Linux, macOS)
- **Components:** Unet Simulator, Unet basic agents, Unet premium agents, basic and premium channel models

4.3. OEM Edition

The OEM edition is the version of UnetStack that runs within a user's modems, including all Subnero smart modems. Additionally, the OEM Edition offers licensing options for users engaged in developing modems. This includes OEM vendors of acoustic modems, researchers involved in modem development, or users operating third-party modems seeking to incorporate UnetStack capabilities into their deployment base. The [S1000-N modem, a collaborative initiative between Subnero and Popoto Modem](#) is an example of a third party modem running the UnetStack.

- **Platform:** OEM platforms
- **Components:** Unet basic agents, Unet premium agents, software drivers

4.4. Developer Tools

The developer tools are available as part of an OEM device and allow you to simulate and develop software for the OEM device. It also lets you run UnetStack on your workstations to connect to and control the OEM device for development and testing of any protocols or applications involving the OEM device. Example use cases include development of protocols at various levels of the network stack, and development of user-defined web-based dashboards. Access to the developer tools is available either as a download from the OEM device's user interface or provided directly by Subnero, with upgrades also supplied by Subnero.

- **Platform:** Workstation (Linux, macOS)
- **Components:** Unet Simulator, Unet basic agents, Unet premium agents, basic and premium channel models

5. Utilizing UnetStack With Your Existing Modems

"Can we use UnetStack with our existing modems?" This question often arises in our discussions. The short answer is yes. However, the integration process varies based on your specific use case, offering multiple methods and levels to incorporate UnetStack with your hardware — be it an acoustic modem, optical modem, wired link or a terrestrial wireless device. UnetStack presents a versatile solution, offering a unified media-agnostic interface capable of supporting multiple underlying devices concurrently, ensuring seamless end-to-end connectivity.

In this section, we delve into various use cases to illustrate how UnetStack integrates with your existing hardware setup as shown in Figure 4. Through practical examples and scenarios, we showcase the adaptability and functionality of UnetStack across different modem types and hardware configurations. This exploration aims to provide insights into the flexibility and diverse integration options UnetStack offers, empowering users to leverage existing hardware in tandem with UnetStack's capabilities for enhanced connectivity and network performance.

NOTE: There may still be scenarios that are not covered in this section. Reach out to us to explore further.



Figure 4. Flexibility of UnetStack OEM Edition

5.1. Use Case 1

Optimized Underwater Acoustic Performance With Full Network Stack Capabilities



Figure 5. Subnero Smart Modems

When your primary focus is attaining optimal end-to-end connectivity for your undersea deployments, the ideal solution lies within Subnero's comprehensive offerings. Our WNC series of underwater acoustic smart modems are meticulously designed to leverage every basic and advanced feature offered by UnetStack. These modems not only excel in delivering top-tier wireless performance in terms of throughput and communication range but also offer a spectrum of configuration options and editions tailored to meet your specific requirements. Refer to Section 7 for details.

5.2. Use Case 2

Integration Of UnetStack With Existing Hardware Platforms Capable of Arbitrary Waveform Transmission

This use case caters to a diverse range of individuals or entities such as:

- A researcher equipped with third-party underwater acoustic modems capable of arbitrary waveform transmission and reception.
- A researcher with a bespoke system for waveform transmission and reception (utilizing components like a DAC & ADC, analog amplifiers, transducer, and/or hydrophone).
- An OEM vendor or organization (e.g. acoustic transponder) aspiring to incorporate communication capabilities into your device without undergoing extensive R&D expenses.
- An enthusiast looking for a starting point to building an acoustic modem.

Irrespective of the scenario, if you have a hardware capable of arbitrary waveform transmission and reception[†] in one of the supported frequency bands, you can utilize the UnetStack OEM edition to build a cutting edge underwater acoustic smart modem. Figure 6 illustrates the basic components of such a solution.

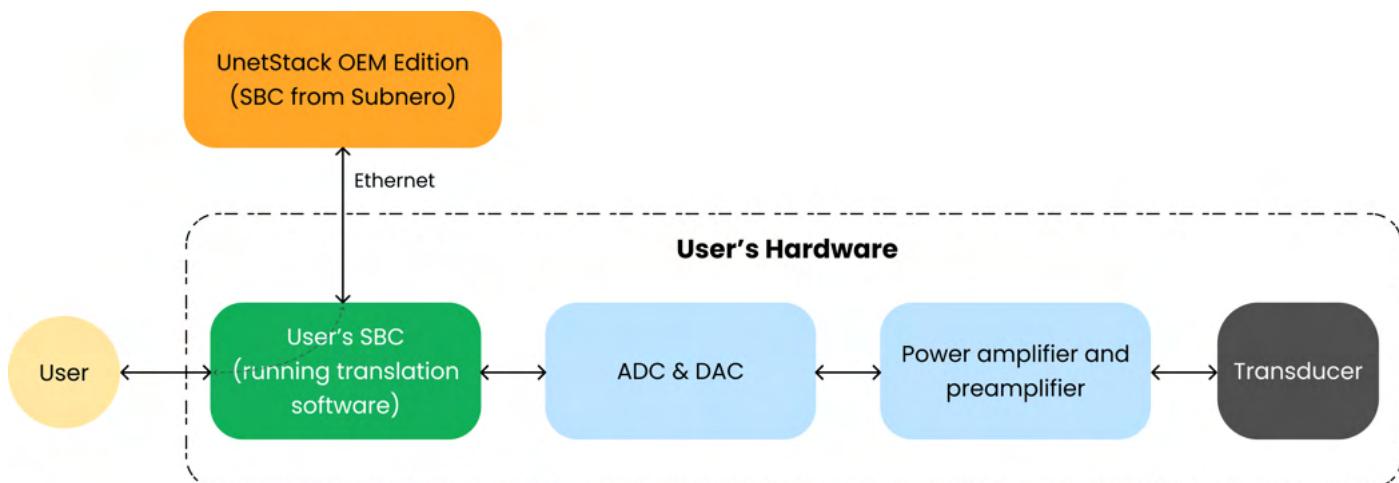


Figure 6. UnetStack OEM Deployment Illustration

The UnetStack OEM edition, licensed to operate on a compatible Commercial Off-The-Shelf (COTS) single-board computer (SBC), constitutes the core of this integration. The SBC hosts the entire UnetStack network stack along with supported physical layer protocols like FH-BFSK, JANUS, and OFDM, coupled with the baseband driver. The hardware interface operates via Ethernet, employing JSON over TCP to stream physical layer waveforms in and out. A software translation layer residing in user's SBC ensures compatibility between this format and the user platform's input and output. Users may also choose to expose the various UnetStack interfaces through the user's SBC. In addition to utilizing UnetStack OEM editions physical layer, user's may also deploy their own physical layer in their SBC and integrate with the UnetStack OEM edition.

Supported COTS SBCs include [nVidia Jetson Orin nano](#) and NXP i.MX8M Plus based SBC (expected availability: 2025) available from Subnero.

Advantages

- ✓ UnetStack's physical layer protocols and a full network stack running on user's hardware.
- ✓ Complete control over your hardware design.
- ✓ Ability to replace any of UnetStack's agents with user's implementation.
- ✓ Optimal utilization of your hardware capabilities.

Note that features such as coherent modulation schemes (e.g. OFDM), two-way ranging, positioning etc. are dependent on the hardware capabilities. The performance of the final solution will depend heavily on the final hardware capability.

[†] must meet recommended requirements. Details available upon request.

5.3. Use Case 3

Enhancing Point-to-Point Links With Networking Capabilities Using UnetStack

This use case caters to scenarios where you possess a point-to-point wireless communication device, like an acoustic or optical modem, commercially available or DIY, primarily equipped with only a physical and/or MAC layer. The goal is to augment these devices with networking capabilities to enable the establishment of a multi-device network, similar to integrating a TCP/IP stack onto an Ethernet network card.

To achieve this, the UnetStack OEM Edition running on a COTS SBC offers a viable solution, omitting the physical layer which already exists in your device. If your device includes a link or MAC layer associated with the physical layer, you can develop a link layer driver to interface the OEM edition with your device's link or MAC layer. An example would be integrating UnetStack OEM edition to an optical or satellite modem to provide a multi-modal network setup.

These flexible approaches enhance your existing point-to-point communication devices, fostering the development of robust, network-enabled solutions tailored to your specific networking needs using UnetStack OEM edition.

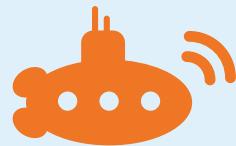
6. Conclusion

Designed with flexibility and ease-of-use in mind, UnetStack allows you to easily develop and configure underwater communication devices and networks. It also helps automate and optimize network management, develop, simulate and test new network protocols, and implement software-defined signaling at the physical layer. Whether utilizing Subnero smart modems or integrating to third-party acoustic, optical, or other wired or wireless devices, UnetStack provides an array of configuration options for diverse applications.

This comprehensive suite of capabilities positions UnetStack as an ideal collection of technologies for extending communication networks underwater. Its adaptability, from foundational development to deployment across varying applications, makes UnetStack a versatile and holistic solution.

7. Resources

- [Subnero Modems](#)
- [UnetStack](#)
- [Handbook](#)
- [Videos](#)
- [Blogs](#)
- [Synchronizing physical clocks among different UnetStack-based modems](#)
- [Scheduling transmissions intelligently in UnetStack enabled modems](#)
- [Frequency band control using UnetStack](#)
- [Converting your laptop into a JANUS modem using Unet audio](#)
- [Community Contributions](#)
- [Relevant Publications](#)
- [Support](#)



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